PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : G11B 7/00

A3

(11) International Publication Number: WO 97/25709

(43) International Publication Date: 17 July 1997 (17.07.97)

(21) International Application Number: PCT/US97/00290

(22) International Filing Date: 3 January 1997 (03.01.97)

(30) Priority Data:

08/583,651	5 January 1996 (05.01.96)	US
08/620,196	22 March 1996 (22.03.96)	US

(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, HU, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, TJ, TM, TR, TT, UA, UG, US, UZ, VN, ARIPO patent (KE, LS, MW, SD, SZ, UG), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).

Published
With international search report.

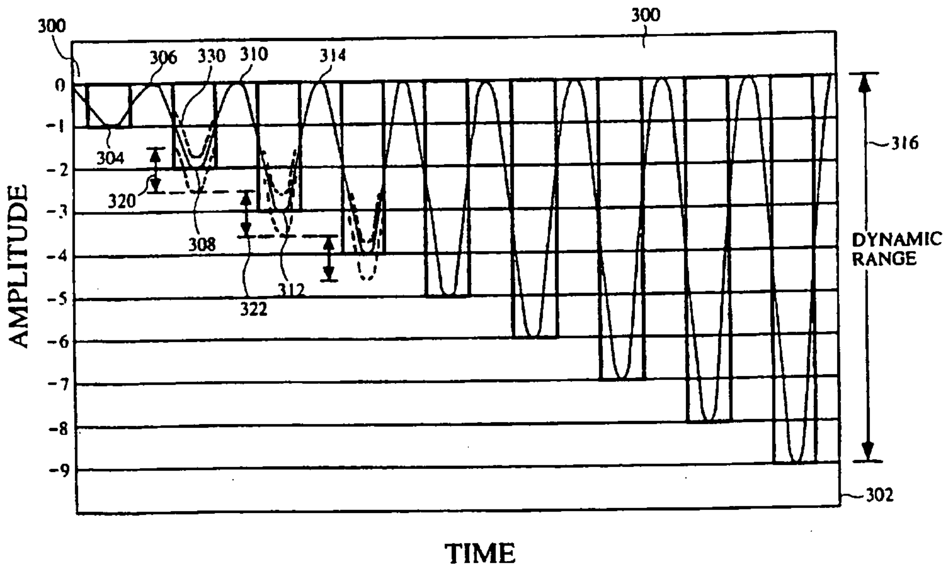
(88) Date of publication of the international search report: 18 September 1997 (18.09.97)

(71) Applicant (*for all designated States except US*): CALIMETRICS, INC. [US/US]; 5901 Christie Avenue #406, Emeryville, CA 94608-193 (US).

(72) Inventors; and
(75) Inventors/Applicants (*for US only*): JOHNSON, Bruce, V. [US/US]; Apartment 22J, 3040 Smyth Road, Berkeley, CA 94704 (US). MCDERMOTT, Gregory, A. [US/US]; 94 Webster Street, San Francisco, CA 94117 (US). O'NEILL, Michael, P. [US/US]; 1652 Santa Clara Street, Richmond, CA 94804 (US). PIETRZYK, Cezary [US/US]; 614 Major Vista Court, Pinole, CA 94564 (US). SPIELMAN, Steven, R. [US/US]; 2032 Delaware Street #9, Berkeley, CA 94709 (US). WONG, Terrence, L. [US/US]; 1845 Pacific Avenue #5, San Francisco, CA 94109 (US).

(74) Agents: VAN PELT, Lee et al.; Hickman Beyer & Weaver, L.L.P., P.O. Box 61059, Palo Alto, CA 94306 (US).

(54) Title: OPTICAL DISK READER



(57) Abstract

The present invention includes a method and apparatus for reading data from an optical information storage disc having an information storage track that includes a plurality of pits, each pit having the capacity to store at least three discrete data levels represented by differing intensities of radiation reflected toward a detector. The information storage track is read and an analog data signal is output which is indicative of the reflectance of the pits. The analog data signal in the vicinity of the location of a pit is sampled and converted to a data signal which is indicative of the reflectance at the location of the sampled pit. The discrete data level stored at the location of the sampled pit level is determined. There is the potential of at least three discrete data levels and each data level corresponds to an associated range of digital signal values. Thus, the data level read from each pit has the capacity to represent more than one bit of information.

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AM	Armenia	GB	United Kingdom	MW	Malawi
AT	Austria	GE	Georgia	MX	Mexico
AU	Australia	GN	Guinea	NE	Niger
BB	Barbados	GR	Greece	NL	Netherlands
BE	Belgium	HU	Hungary	NO	Norway
BF	Burkina Faso	IE	Ireland	NZ	New Zealand
BG	Bulgaria	IT	Italy	PL	Poland
BJ	Benin	JP	Japan	PT	Portugal
BR	Brazil	KE	Kenya	RO	Romania
BY	Belarus	KG	Kyrgystan	RU	Russian Federation
CA	Canada	KP	Democratic People's Republic of Korea	SD	Sudan
CF	Central African Republic			SE	Sweden
CG	Congo	KR	Republic of Korea	SG	Singapore
CH	Switzerland	KZ	Kazakhstan	SI	Slovenia
CI	Côte d'Ivoire	LI	Liechtenstein	SK	Slovakia
CM	Cameroon	LK	Sri Lanka	SN	Senegal
CN	China	LR	Liberia	SZ	Swaziland
CS	Czechoslovakia	LT	Lithuania	TD	Chad
CZ	Czech Republic	LU	Luxembourg	TG	Togo
DE	Germany	LV	Latvia	TJ	Tajikistan
DK	Denmark	MC	Monaco	TT	Trinidad and Tobago
EE	Estonia	MD	Republic of Moldova	UA	Ukraine
ES	Spain	MG	Madagascar	UG	Uganda
FI	Finland	ML	Mali	US	United States of America
FR	France	MN	Mongolia	UZ	Uzbekistan
GA	Gabon	MR	Mauritania	VN	Viet Nam

OPTICAL DISC READER

BACKGROUND OF THE INVENTION

The present invention relates generally to an apparatus and method for providing high capacity and fast transfer speed optical disc data storage.

The compact disc (CD) has become the standard for high-speed, high-capacity Read Only Memory (ROM). In addition, there are also recordable (CD-R) and rewritable (CD-RW) CD technologies available. Advances in CD technology have increased both the speed of data transfer and the amount of data which a single CD can hold. Progress has been made in data transfer speed by spinning the disc faster during read and by more densely packing data in a two-dimensional space. Packing data more densely has also resulted in increased data storage capacity.

Current methods of optical data storage encode information on the surface of a CD using pits of constant depth but varying length alternating with lands of varying length. A detailed description of this method may be found in the Compact Disc Handbook, by Ken C. Pohlmann A-R Editions, Inc. Madison WI 1992, which is incorporated here by reference. The lengths of the pits and lands encode the data. The laser that reads the data is focused on an area of the disc surface which is characterized by a pit or a land. If the laser is focused on a pit, then the difference in the optical path length of the light reflected from the bottom of a pit from the optical path length of the light reflected from the surrounding surface of the CD causes an interference effect and the intensity of the light reflected from the disc is decreased. The intensity of the light reflected from the disc therefore produces a signal in a detector which corresponds to a pit or a land. Each edge or transition from pit to land or from land to pit is detected and recognized as a logical 1 (one). The length of pit or land between edges represents a series of logical 0's (zeroes). The number of zeroes in the series is proportional to the length of the region between edges. Conventional CD readers operate by determining the exact point of each transition from pit to land or from land to pit.

The CD is typically created from a metal stamper that bears an inverse pattern of the data-encoding pits and lands. A material such as molten polycarbonate is injected into a mold containing the stamper to produce the CD. After removal of the cooled polycarbonate disc, the data-bearing side of the disc is typically coated with a thin layer of aluminum to increase the reflectivity of the surface. The aluminum is usually coated by a protective layer of lacquer. The data on the disc is read by focusing a laser beam through the polycarbonate side of the disc onto a spiral track that contains the pits and lands of varying length. As the disc rotates through the focus of the laser beam, electromechanical servo systems keep the laser beam on track and in focus.

Another method is also used to effect a change in reflectivity at the desired location of a pit on the surface of a disc. Instead of creating a physical pit in the surface of the disc, the index of refraction of the disc material in the region of the desired pit location is varied from the index of refraction of the disc material in a land region. This may be done, for example, by providing at least one layer of the disc which is made from a material that can change its crystalline properties and therefore its index of refraction upon heating, a so-called phase-change material. The change in the index of refraction in the material in a region changes the reflectivity in that region. Upon exposure to a heat source, typically a focused laser beam, the material can be made to encode data in the form of varying lengths of high-reflectivity regions alternating with varying length regions of low-reflectivity. This method is similar in concept to the aforementioned pit/land method with regard to encoding a logical 1 (one) in the form of the edges, and logical 0's (zeroes) in the form of the space between the edges. Yet another method of changing the reflectivity of the disc at a desired pit location is to provide a dye which darkens when irradiated by a writing laser. This method is currently used for CD-R systems.

In an effort to further improve the storage density of CDs, a number of techniques have been proposed that permit multiple bits of information to be stored in a single pit. Discs having variable depth pits could store more than a single bit of information if each different pit depth corresponds to a different data level. It should also be noted that in addition to variable level pits which are physically formed by stamping or removing material from the

disc, other types of variable level data pits may be formed by regions at the surface of the disc which have a material with a different index of refraction than the surrounding material, or which have a material with a different reflectivity than the surrounding material. Thus, the term "pits" is used to refer to areas on the disc on which data is stored, including pits that produce in any way a different optical path length between the pit surface and the disc surface, or pits formed by changing the reflectivity of the disc surface at the pit locations.

In the case where physical pits and lands are formed, the index of refraction of the disc does not change; rather a pit of carefully selected dimensions is used to modulate the amount of light that is reflected back to the light-sensitive detector. The reading laser, when focused on a pit, is such that a portion (approximately half) of the focused light falls in the pit while the other portion falls outside on the surrounding land region. The depth of the pit is approximately one quarter of the reading laser wavelength so that upon reflection, a total of a half-wavelength shift between the two portions of the beam results in one portion being out of phase with the other. This results in destructive interference between the two portions of the querying light beam and hence little light-intensity is measured by the light-sensitive detector when a pit is encountered. Thus, edges or transitions from pit to land are easily detectable as transitions in light intensity between two states: bright and dark (note that it is desirable to provide some light intensity even in the presence of a pit so as to allow the focus and tracking servos to remain operational). When the pit consists of a portion of material with a different index of refraction, destructive interference at the pit area is similarly caused by the difference in the optical path length traveled by light which travels through the pit location.

Faster data transfer as well as higher information storage capacity could be achieved if, instead of merely detecting the edges or transitions between two states, pit and land, a detector could be developed which could resolve multiple levels of encoded data at each point on the disc. Throughout this specification, detecting more than two signal levels from pits with more than two levels is referred to as detecting "multiple" levels from "multiple" level pits. Such a detector could distinguish between more than the two disc surface levels, pit and land. If n different levels of pits are distinguished, then log2 (n) bits of information

could be stored in the area of a minimum-length pit. Various numbers of pit levels (n) could be used. For example, 8 different levels would encode 3 bits, 16 different levels would encode 4 bits, 32 different levels would encode 5 bits, and so on; values of n that are not powers of two would encode a fractional number of bits, e.g., 9 different levels would encode 3.17 bits per pit. To further increase the information capacity of the CD, rather than following a variable-depth pit by a land region, another variable-depth pit could immediately follow the preceding one, and so on, such that each variable-depth pit immediately abuts each adjacent variable-depth pit. Furthermore, additional information capacity could be achieved by not restricting the variable-depth pits to n discrete levels, but by allowing them to be encoded and read in a continuous, or analog, fashion.

One method of detecting multiple level pits is the laser-feedback method of depth detection as described in U.S. Patents 5,029,023; 5,235,587; and 5,260,562 issued to Bearden and O'Neill. In the laser feedback method, the laser itself acts as a phase detector for the reflected light from the disc. A portion of the reflected light from the disc reenters the laser cavity, causing the intensity of the laser output to vary as a function of the optical path length of the reflected light. Since the optical path length of the reflected light is affected by the depth of the pit which reflected it, it is possible to precisely measure changes in pit depth. Changes in pit depth, however, are determined from the laser's intensity, not from the intensity of the reflected light from the disc as described in the present invention. A disadvantage of the laser feedback interferometer method is that the laser intensity modulation is affected by the absolute distance between the laser and the reflective surface of the disc. Variations in the flatness of the disc, as well as wobble caused by spinning of the disc, therefore cause modulation of the laser intensity.

Because of its reliance on resolving small pit depth differences, a multiple pit level reader would be vulnerable to noise caused by imperfections in the manufacture of the disc. Such noise might change the data level read.. For example, if, in the disc manufacturing process, all of the pits on certain portions of the disc are not formed to a sufficient depth as a result of uneven cooling or some other slowly varying effect, then those pits would each be read as an incorrect data level. In a two level system, this effect would not cause a problem

since the signal would still transition through the single threshold at almost the same time. In a two level system, it is also possible to automatically adjust the threshold for slowly varying defects by filtering out the DC and low frequency components of the signal. For a multilevel system, some method of adjustment would be required to compensate for disc defects that would otherwise cause misreading when the multiple threshold levels are applied.

It would be advantageous if, instead of detecting only two levels of depth, i.e. pit or land, a system could be provided which could resolve more than two depth levels. It would also be desirable if such a system's output was not sensitive to the absolute distance between the reading laser and the disc surface. It would furthermore be desirable if such a system could compensate for changes in the characteristics of the disc which is being read which represent noise.

SUMMARY OF THE INVENTION

The present invention relates to a method and apparatus for reading multiple levels of intensity of light reflected from a CD with variable depth pits, with an index of refraction modulated material, or with any material that modulates the optical path length of the reflected light or alters the reflectivity of the CD surface in any way. Accordingly, the present invention reads more information from the same amount of CD surface area by, instead of merely detecting edge transitions between pits and lands, providing a CD reader which can detect multiple levels of pits. The interference between the portion of the beam that is incident inside of the pit and the portion of the beam that is incident outside of the pit on the surrounding surface of the CD may change the light intensity back-reflected from the disc or the reflectivity of the disc surface may be varied to change the light intensity back-reflected from the disc. The changes in light intensity are monitored by a light-sensitive detector which outputs a data signal. A digital signal processor including a multi-bit analog to digital converter determines data levels from the data signal.

The present invention includes a method for reading data from an optical information storage disc having an information storage track that includes a plurality of pits, each pit

having the capacity to store at least three discrete data levels represented by differing intensities of radiation reflected toward a detector . The information storage track is read and an analog data signal is output which is indicative of the reflectance of the pits. The analog data signal in the vicinity of the location of a pit is sampled and converted to a data signal which is indicative of the reflectance at the location of the sampled pit. The discrete data level stored at the location of the sampled pit level is determined. There is the potential of at least three discrete data levels and each data level corresponds to an associated range of digital signal values. Thus, the data level read from each pit has the capacity to represent more than one bit of information.

The present invention further includes an apparatus for reading data from an optical information storage disc having an information storage track that includes a plurality of pits, each pit having the capacity to store at least three discrete data levels represented by differing intensities of radiation reflected toward a detector. An analog to digital converter is configured to sample an analog signal indicative of the reflectance of the pits and configured to provide as an output a digital signal which includes a plurality of bits for each sample. A digital signal processor is configured to determine a discrete data level from the digital data signal, there being the potential of at least three discrete data levels, wherein each potential data level corresponds to an associated range of digital signal values. Thus, the data level read from each pit has the capacity to represent more than one bit of information.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated in and constitute a part of the specification, schematically illustrate a preferred embodiment of the invention and, together with the general description given above and the detailed description of the preferred embodiment given below, serve to explain the principles of the invention.

FIGURE 1 shows the basic-functional blocks of a prior art CD reader.

FIGURE 2A shows the basic constituents of a digital variable-depth optical disc reader in accordance with one embodiment of the present invention.

FIGURE 2B shows the basic constituents of an analog variable-depth optical disc reader in accordance with a second embodiment of the present invention.

FIGURE 3 shows an idealized light-sensitive detector output in response to a return-to-zero (RTZ) variable pit-depth pattern illustrating dynamic range and windows.

FIGURE 4 is graph illustrating a representative data signal plotted verses time with window levels shown.

FIGURE 5 shows an example of a synchronization and calibration pattern which is used in one embodiment of the present invention.

FIGURE 6 shows an example of a calibration pattern which is used in one embodiment of the present invention.

FIGURE 7 is a graph which shows a comparison of an idealized and actual light-sensitive detector output in response to a RTZ variable pit-depth pattern.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Reference will now be made in detail to a preferred embodiment of the invention, which is a system and method for reading multiple levels of variable intensity light produced by a CD which is encoded with multiple level pits. An example of the preferred embodiment is illustrated in the accompanying drawings. While the invention will be described in conjunction with that preferred embodiment, it will be understood that it is not intended to limit the invention to one preferred embodiment. On the contrary, it is intended to cover alternatives, modifications, and equivalents as may be included within the spirit and scope of the invention as defined by the appended claims.

FIGURE 1 shows the basic functional blocks of a conventional prior art CD reader. A CD-ROM 100 is read by an optical head 110. A set of servos 120 provide focusing and tracking control for an optical head 110. Optical head 110 contains opto-mechanical

components to produce a laser beam, focus the beam on the disc, maintain the focus of the beam on a track of data, and read the data stored on the disc. A spindle motor 130 spins CD-ROM 100 at a speed which enables optical head 110 to scan the disc and read the dark and light areas created by the pits and lands. A digital signal processing unit 140 receives the signal from optical head 110 and determines where each transition from pit to land or vice versa is located. Since only two levels are recorded on a conventional CD-ROM, the function of digital signal processing unit 140 is simply to determine the timing of the transitions. The timing of each transition determines the length of the pits and lands. The resulting pattern of ones and zeroes is processed according to the error correction algorithm used in the system. Thus, digital signal processing unit 140 sets a single threshold and determines exactly when the signal crosses that threshold in order to determine the exact point of transition between a pit and a land. Determination of the transition points gives the length of the pits and lands from which the data is determined.

A drive control unit 150 specifies where data is to be located and read from the disc and a system control unit 160 manages the communication between the variable-depth optical disc reader and the computer. A computer interface 170 transmits data to a computer and receives commands from the computer.

FIGURE 2A shows the basic constituents of a digital variable-level optical disc reader. A pit depth modulated disc, or PDM-ROM 200 is read by an optical head 110. A set of servos 120 provide focusing and tracking control for an optical head 110. Optical head 110 contains opto-mechanical components to produce a laser beam, focus the beam on the disc, maintain the focus of the beam on a track of data, and read the data stored on the disc. The variable-intensity signal produced by variable-depth pits and their surrounding lands is measured by a light-sensitive detector in the optical head 110. This detector converts the variable-intensity light signal into a data signal which is a variable-amplitude electrical signal that represents the data. In certain embodiments, the electrical signal is used to keep the optical head in focus and on track as well as to read the data.

A spindle motor 130 spins PDM-ROM 200 at a speed which enables optical head 110 to scan the disc and read the level of reflected light at successive locations. A multiple bit

analog to digital (A/D) converter 220 converts the analog signal obtained from optical head 110 into a digital signal having more than one bit per pit location. The A/D conversion is performed in one embodiment by feeding the data signal simultaneously to the inputs of n comparators, each of which are also connected to n equally spaced reference voltages, thus forming a "ladder". Each comparator with an input voltage greater than its reference voltage returns a high output signal, or is "activated"; otherwise a low signal output is obtained. The digital output of the ladder corresponds to the highest "rung" activated. In certain embodiments, the gain of the signal input into the A/D converter is controlled according to the measured dynamic range of the data signal as determined by a series of calibration pits as described below or as determined from the maximum and minimum levels of the data signal. In certain embodiments, the reference voltages connected to the n comparators are also variable so that the reader disc irregularities may be compensated for during the digitizing process.

A digital signal processing unit 240 receives the digital signal generated by multiple bit analog to digital converter 220 and processes the signal to determine the data levels stored by the pits which are being read. It is preferred that the digitized signal include more bits per sample than the number of bits which are represented by the potential data levels, so that the signal can be digitally analyzed according to ranges which include more than one digitally represented signal value. (However, in certain other embodiments where extensive analog signal processing is performed to adjust both the dynamic range and the reference voltage in the analog to digital converter, it is possible that certain ranges may include only one digitized digital signal value.) Digital signal processing unit 240 also makes corrections for various effects including intersymbol interference.

In one embodiment which includes ten potential data levels, including nine different pit levels and land, analog to digital converter 220 most preferably provides an eight bit digital signal to digital signal processing unit 240. For such a ten data level system, a digital signal which contains at least 8 bits per sample, or about 5 bits per sample more than the number of bits in the total potential number of data levels is most preferred. More than about 16 bits per sample for such a signal is impractical due to cost and speed considerations, and

less than 5 bits per sample would not provide enough information to correct for errors and allow for intersymbol interference. Too few bits also causes more errors statistically to occur when the data level is determined by determining the signal range in which the digital signal falls. A practical range is between 6 and 12 bits per sample.

For other numbers of potential data levels, it is most preferred that the number of bits included in the digital signal is about 5 bits more than the number of bits represented by the number of data levels. At least 2 more bits is required for the system to be accurate and between 2 bits and 8 bits is a practical range. More than 8 bits may be required in some cases, if a sufficiently fast analog to digital converter is available. It is also taken into consideration when choosing the number of bits in the digital signal the availability of analog to digital converters in mostly even number bits. Thus, in the example given above including 10 potential levels, or 3.2 bits, an 8 bit digital signal is a signal with 5 more bits and is most preferred. A 5 bit digital signal would be the minimum practical with a 6 bit signal more preferable because of the greater availability of 6 bit analog to digital converters. A 12 bit signal would be the upper practical bound and at greater than 16 bits, it would be difficult to meet the speed requirements for processing.

Digital signal processing unit 240 is connected to a synchronization processor 242 which synchronizes the sampling of the pits with the pit locations. Synchronization processor 242 is shown separately from digital signal processing unit 240, but in certain embodiments, synchronization processor 242 is combined with digital signal processing unit 240. In contrast to digital signal processing unit 140 which sets a single threshold and determines exactly when the signal crosses a single threshold in order to determine the exact point of transition and therefore the length of a pit or land, digital signal processing unit 240 synchronizes the sampling of multiple bit analog to digital converter 220 with the disc pit pattern and measures the signal level at each pit location to determine the depth of the pit at a given location. The importance of synchronization processor 242 may be understood by considering a level 2 pit followed by a level 8 pit. The read signal would transition between the darkness levels representing the two pits and it is necessary to sample the signal not at a point where an intermediate value is obtained, but instead at a point where the signal has

completely reached the level corresponding to the data recorded at each location.

In one embodiment, synchronization processor 242 operates by reading a series of synchronization patterns and using a phase locked loop to synchronize the sampling clock with the synchronization patterns. In one embodiment, the synchronization patterns are detected using an analog threshold detector. In other embodiments, the synchronization patterns are recognized from the digital signal. In still other embodiments, synchronization patterns are not provided and synchronization processor 242 operates by processing the data signal provided by multiple bit analog to digital converter 220 and synchronizing according to either the peaks, the transitions, or the troughs found in the signal. In some embodiments, a phase locked loop is used to synchronize the sampling clock with the portion of the signal which represents data recorded in a pit. If peaks and troughs are identified, the phase of the sampling clock is adjusted so that samples are taken at the point s near the peaks and troughs which represent the stored data. The relative position of these points is completely predetermined in some embodiments and it is fine tuned in other embodiments. If transition points are identified, then the phase of the sampling clock is adjusted so that samples are taken away from the transition points in the vicinity of the peaks and troughs representing data.

It is most preferred that about 4000 to 5000 synchronization patterns be provided per circumference of the disc, in order to keep the sampling clock properly synchronized. This corresponds to about 1 synchronization pattern every 100 pits in the center of the disc, 1 pattern every 50 pits in the inner portion of the disc and 1 pattern every 150 pits in the outer portion of the disc. A practical range of synchronization pattern frequency is about 2000 to 10000 synchronization patterns per circumference. A sufficient frequency of patterns must be provided to enable the clock to remain synchronized, but too great a frequency results in reduced data storage capacity.

Digital signal processing unit 240 is also connected to a calibration processor 244 which provides windows which are calibrate d or scaled according to the measured characteristics of the signal obtained from a specific disc which is being read. The calibrated windows are then used to determine the signal levels at each pit. Each window defines an

upper and lower bound for the signal which corresponds to the data level associated with the window. In one embodiment 8 different windows are defined corresponding to 8 different data levels or 3 bits of data. In another embodiment, 10 different windows are defined corresponding to 10 different data levels. This provides room for the storage of 3 bits of data, as well as some overhead room for error correction. Calibration processor 244 is shown separately from digital signal processing unit 240, but in certain embodiments, calibration processor 244 is combined with digital signal processing unit 240. In one embodiment, calibration processor 244 performs its scaling function by reading a special calibration pattern which includes pits which return the highest and lowest signal levels when read. The highest and lowest signal levels thus define the dynamic range of the signal in a region of the disc surrounding the calibration pattern. Based on the dynamic range which is determined, signal window levels are defined as is described below. In other embodiments, calibration processor 244 determines the dynamic range of the data signal obtained from optical head 110 by analyzing the data itself to determine the maximum and minimum data signals.

In another embodiment calibration processor 244 reads a special calibration pattern which includes pits which return the highest and lowest signal levels, as well as all intermediate signal levels which correspond to intermediate data levels. Calibration processor 244 not only scales the signal to compensate for changes in the dynamic range of the data signal obtained from optical head 110, but also compensates for variations in the distances between each individual signal level. The signal window levels thus defined precisely determine the signal level, even when nonlinear variations are present.

As in the two level pit reader, a drive control unit 150 specifies where data is to be located and read from the disc and a system control unit 160 manages the communication between the variable-depth optical disc reader and the computer. A computer interface 170 transmits data to a computer and receives commands from the computer.

In contrast to the CD-ROM reader shown in FIGURE 1, the pit depth modulated ROM reader or PDM-ROM reader shown in FIGURE 2A functions to determine the actual data level at certain points on a pit-depth modulated disc corresponding to pits instead of

merely determining the transition points between pits and lands. Therefore, instead of merely identifying the timing of a transition to a pit or a land, the PDM-ROM reader shown in FIGURE 2A returns actual data levels through computer interface 170. The output from digital signal processing unit 240 is thus fundamentally different from the output of digital signal processing unit 140. Digital signal processing unit 140 determines changes in times which in turn determines the length of pits and lands and the lengths of the pits and lands represent a series of 1's or 0's. In contrast, the output of digital signal processing unit 240 consists of a series of numbers which represent the level of each pit as it is being read.

If the data signal is encoded in an analog fashion, the data signal does not have to be converted to a digital signal; the signal can be simply used in an analog fashion as, for example, by a radio or television. Such an analog system is shown in FIGURE 2B, where an analog signal processor 241 processes the data signal from optical head 110 and transfers the signal to output 242.

Once the data signal from optical head 110 is sampled at the correct time as a result of the operation of synchronization processor 242 , the depth of each pit can be determined from where the data signal falls within its full, or dynamic range. The dynamic range is the full range over which the signal can vary: from its lowest value (for the deepest pit) to its highest value (for a land). FIGURE 3 illustrates how the dynamic range can be broken into a number of windows. FIGURE 3 shows a data signal 300 from an ideal detector reading and ideal disc which has sequentially detected nine different level pits with a land located between each pit. Note that synchronization processor 242 causes the data signal to be sampled successively at each maximum and minimum point. As the depth of each pit increases, the intensity of data signal 300 at the pit location decreases. Data signal 300 returns to its maximum value between each pit as a result of reading each land between pits.

FIGURE 3 illustrates a graph of data signal 300 for an idealized system for a return to zero test pattern. The idealized pit depth pattern being read is shown by curve 302. A first pit 304 has a depth corresponding to an amplitude negative one and is followed by a land 306. A second pit 308 has a depth which corresponds to a amplitude negative two and is followed by a land 310. Likewise, a pit 312 has a depth which corresponds to an

amplitude of negative three and is followed by a land 314. Similarly, each pit is followed by a land, hence the pit pattern is referred as a return to zero test pattern since the signal returns to zero at the location of each land located between pits. It should be noted that the present invention is intended to read either pits arranged next to lands or pits arranged next to each other with no lands in between. The full dynamic range 316 of the system is shown to extend from an amplitude of zero to an amplitude of -9. This dynamic range is broken down into ten levels, each corresponding to a data level. Each data level is defined by a window which includes a maximum and a minimum amplitude level. For example, a window 320 is shown extending from amplitude -1.5 to amplitude -2.5. Any signal detected at a level between these two amplitudes is interpreted as a signal which corresponds to the third data level. Likewise, a window 322 is shown defined by amplitude -2.5 and amplitude -3.5. Any signal falling between these two amplitudes will be interpreted to correspond to the fourth data level.

FIGURE 4 further illustrates the windowing and sampling process. A signal 410 has been successfully sampled in synchronization with the reading of a series of pits at times 1, 2, 3, 4, and 5. Note that if synchronization processor 242 does not synchronize the sampling and the sampling occurs at other times, significantly different digitized values which correspond to transitional signal levels values and not to pit signal levels would result. For example, a point 420 is sampled at time 3 and falls within window 4. If the sample had been taken at some other point between time 3 and time 4, then it could have fallen within either window 2 or window 3. In the example shown, the samples taken at times 1, 2, 3, 4, and 5 correspond to data levels 5, 3, 4, 1, and 2, respectively.

In order to assure that the samples are taken during time intervals which correspond to pits which are being read and not time intervals corresponding to transitional periods, the sampling clock is appropriately synchronized to the pit pattern on the disc. This synchronization of the sampling clock is accomplished using a timing-synchronization pit pattern that allows the disc reader's system to determine whether the sampling clock needs to be sped up or slowed down. FIGURE 5 illustrates a synchronization pattern 500 which is used to synchronize pits on a disc. Synchronization pattern 500 consists of three lands

followed by 6 maximum depth pits followed by three lands. Other synchronization patterns could be used, including patterns which contain fewer numbers of pits or which contain intermediate pit levels. It is important , however, that the synchronization pattern used is not often duplicated in the data being read or problems could result from portions of the data being read as part of a synchronization pattern or vice versa.

Synchronization processor 242 checks the data being read by optical head 110 for a synchronization pattern and synchronizes a sampling clock according to their occurrence. In certain embodiments, A phase locked loop is used to synchronize a clock according to the synchronization pattern location. In one embodiment, transitions within a single synchronization pattern such as falling edge 502 and rising edge 504 are used to synchronize the clock. In other embodiments, synchronization patterns are periodically located on the disc and the exact intervals between transitions within successive patterns are used to synchronize the sampling clock.

Synchronization pattern 500 is suitable for synchronization using a single pit without digitizing the data signal. A threshold detector within synchronization processor 242 determines when the signal value has fallen below a certain value and a timer within synchronization processor determines when the signal has remained below the threshold for greater than a certain period of time. Once that period of time is exceeded, synchronization processor 242 begins to look for a rise in the data signal. When the rising edge of synchronization pattern 500 is detected, the sampling clock phase is adjusted relative to that edge so that the samples will be taken in phase with the pit locations. As long as the data signal does not stay below the threshold for longer than the time limit, portions of the data signal will not be misread as a synchronization pattern.

In other embodiments, synchronization processor 242 detects the synchronization after digitizing the pattern and recognizing a certain code in the pattern. In such embodiments, synchronization processor 242 either synchronizes on an edge provided within the pattern or on pairs of edges within a single pattern or found in multiple patterns.

As mentioned above, data signal 300 shown in FIGURE 3 is an idealized output from a disc with idealized pits, represented by curve 302. In an actual manufactured disc,

the levels would not exactly correspond to these idealized levels. For example, the actual output levels could correspond to the signal levels shown in the dashed curves. For example, pit 330 is shown as a shallower pit than ideal pit 308 and pit 340 is a deeper pit than ideal pit 308.

In certain embodiments, the full dynamic range of the pits, and hence the locations of the windows within that dynamic range are not fixed. By using a set of calibration pits arranged in a calibration pattern, the full dynamic range is measured at various local areas on the disc and the windows are adjusted accordingly for the pits located in that area as the disc is being read. In one embodiment, the calibration pits are a series of alternating pits corresponding to a land and the deepest pit. The signal from these pits represents the full dynamic range of the pits in that local area. The window levels are then scaled to fit within that dynamic range. This type of calibration pattern may also be used as a synchronization pattern, as is described below.

In certain embodiments, the same set of pits are used for both synchronization and calibration. Since synchronization pattern includes both the maximum and the minimum signal values, data samples taken within synchronization pattern 600 may be used to determine the dynamic range for the local region of the disc surrounding synchronization pattern 600. The window levels are then re-scaled to fall within the measured dynamic range.

FIGURE 6 illustrates a multi-level calibration pattern 600 used in certain embodiments to calibrate each window on a disc. Calibration pattern 600 steps through each pit level, providing three pits in a row for each level. In one embodiment, window boundaries are determined by calibration processor 244 by defining each boundary to be equidistant between the two nearest measured levels. For example, if a set of calibration pits is read with signal values of 0, -0.6, -1.2, -2.0, -2.8, -3.6, -4.6, -5.6, -6.8, and -8.1, this information is used to compress the dynamic range and adjust the windows. For example, the upper window level for pit depth 3 is determined by calculating half the difference between the signal level corresponding to pit depth 3 and the signal level corresponding to pit depth 4. The lower window level for pit depth 3 is determined by calculating half the

difference between the signal level corresponding to pit depth 3 and the signal level corresponding to pit depth 2.

In the example given above, the signal level for pit depth 3 is -1.2. (Note that the first pit level corresponds to land and is 0.) The signal level corresponding to pit depth 2 is -0.6. Since half the difference between these two signal levels is 0.3, the lower window for pit level 3 is set at -0.6 - 0.3 = -0.9. Similarly, half the difference between -1.2 and -2.0 is 0.4 and so the upper window for pit level 3 is set at -1.6. This allows the reader to adapt to variations due to its own optical, mechanical, and electrical performance as well as to variations in the disc caused by variations in the stamper or by other factors present in the replication process.

Physical variations in the reader as well as physical variations in the reader influence a physical function which transform the exact signal values corresponding to the data levels which were stored to the actual signal levels which are read. In the above described calibration process, nonlinearities in this physical function are compensated. In certain embodiments, only a single dynamic range measurement is provided and the window levels are linearly fit within the range.

A calibration pattern such as calibration pattern 600 is also used in certain embodiments to determine the number of data levels which are represented on the disc. For example, different quality discs may be capable of different numbers of pit depth modulated levels. By counting the number of steps included in calibration pattern 600, the reader determines the number of potential data levels stored at each pit location. Thus, the reader can automatically distinguish between different discs encoded with different pit depth modulation schemes that include different numbers of levels and determine windows appropriately.

In one embodiment, a single calibration pattern similar to calibration pattern 600 which contains signal levels corresponding to each data level is provided at the beginning of a disc. By setting window boundaries using such a calibration pattern which contains every data level, nonlinearities in the physical function which maps the signal levels to the data levels are compensated. Once that is done, the calibration patterns or synchronization

patterns similar to synchronization-pattern 500 are used by calibration processor 244 to scale the windows. Thus, the relative size of each window to the other windows is defined by a detailed calibration which uses a detailed calibration pattern which produces a data signal for each pit level, and then the window levels are later scaled to fit within a dynamic range which is determined from a simple synchronization pattern which need only include data signals for the highest and lowest data levels. In other embodiments, detailed calibration patterns are provided periodically so that calibration processor 244 can redefine the windows.

FIGURE 7 illustrates actual data read from a disc containing 10 different pit depths, including land. Curve 700 plots the actual data and curve 710 plots an ideal RTZ pit pattern for comparison. Certain of the pits shown in curve 700 are deeper than the ideal pits while others are more shallow. Synchronization processor 242 reads synchronization patterns contained on the disc to ensure that samples are taken at the correct times and calibration processor 244 reads calibration patterns so that the data is digitized to the correct level.

Some variation in the signal level associated with a specific pit level may occur as a result of intersymbol interference. Intersymbol interference is caused by the interference of light reflected from the pit being read with light reflected from pits located adjacent to the pit which is being read. It is possible to pre-compensate for this effect during mastering by varying a pit's depth to account for signal contributions from the neighboring pits. Alternatively, it is possible to compensate for intersymbol interference by further adjusting the Digital to Analog Converter parameters or conditioning the analog or digital signal to compensate for variations in intensity caused by intersymbol interference.

After the signal has been assigned to different pit-depth levels, the signal can be decoded so that the originally stored data is recovered. The decoding process typically, but not necessarily, includes removing channel coding, checking and correcting for errors, and de-interleaving the data. Intersymbol interference may also be compensated for in this step. These functions are also performed by the digital signal processor 240. The channel coding is designed to take full advantage of the abilities of the storage system. In the case of current CD-ROM, an 8-bit word is channel encoded into a series of 1's and 0's that meets the following criteria: there are at least two and no more than ten 0's between each 1. Since on a

current CD-ROM the 1's are physically encoded on the disc by a transition from pit to no-pit or a transition from no-pit to pit, the above criteria ensure that the transitions neither occur too close together nor too far apart in order to stay within the limitations of the system. In the case of variable-depth optical discs, the channel encoding also ensures that the physically encoded data can be clearly read by the player. For example, the sequence of levels written on the disc could require that no two adjacent pits (other than pits within calibration patterns or synchronization patterns) have the same depth. On the disc, there is also information designed to locate and correct errors. This information along with the interleaving of data, the spreading of a data block over a larger area of the disc by breaking up the block and interleaving it with other similarly segmented blocks, guarantees that the data read from the disc is a true representation of the original data.

In summary, a method and apparatus for reading multiple levels of intensity of light reflected from a CD has been described.

The foregoing description of the preferred embodiment of the invention has been presented for purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise form disclosed, and many modifications and variations are possible in light of the above teaching. The preferred embodiment was chosen and described in order to best explain the principles of the invention and its practical applications to thereby enable others skilled in the art to best utilize the invention and various embodiments, and with various modifications as are suited to the particular use contemplated. It is intended that the scope of the invention be defined only by the appended claims.

CLAIMS

1. A method for reading data from an optical information storage disc having an information storage track that includes a plurality of pits, each pit having the capacity to store at least three discrete data levels represented by differing intensities of radiation reflected toward a detector comprising:

reading the information storage track and outputting an analog data signal indicative of the reflectance of the pits;

sampling the analog data signal in the vicinity of the location of a pit;

converting the analog data signal to a digital data signal which is indicative of the reflectance at the location of the sampled pit and which includes a plurality of bits for each sample;

determining the discrete data level stored at the location of the sampled pit from the digital data signal, there being the potential of at least three discrete data levels, wherein each data level corresponds to an associated range of digital signal values;

whereby the data level read from each pit has the capacity to represent more than one bit of information.

2. A method as recited in claim 1 further comprising the step of dynamically calibrating the ranges of digital signal values, wherein the dynamic calibration includes directly or indirectly determining a signal range corresponding to each of the potential data levels, wherein the determined signal ranges are used in determining the data level read from a pit .

3. A method as recited in claim 2 wherein the calibration step includes reading a calibration pattern on the disc, the calibration pattern including a plurality of calibration pits.

4. A method as recited in claim 3 wherein the calibration pattern includes a calibration pit corresponding to a highest data level and a calibration pit corresponding to a lowest data level to facilitate the determination of a dynamic range of the analog data signal.

5. A method as recited in claim 3 or claim 4 wherein each discrete data level has a corresponding calibration pit in the calibration pattern to facilitate the determination of the signal range corresponding to each of the various data levels.

6. A method as recited in any one of claims 2-5 wherein the calibration step includes scaling the signal ranges according to the dynamic range of the analog data signal.

7. A method as recited in any one of claims 2-5 wherein the calibration step includes scaling the signal ranges according to the dynamic range of the digital data signal.

8. A method as recited in any one of claims 2-5 wherein the calibration step includes adjusting the dynamic range of the analog data signal before the analog data signal is converted to a digital data signal based on the measured dynamic range of the calibration pattern.

9. A method as recited in any one of claims 2-8 wherein the calibration pattern includes information indicative of a potential number of discrete data levels that the pits may include, the method further comprising the step of identifying the number of discrete data levels and determining the signal ranges accordingly.

10. A method as recited in claim 1 further comprising the steps of:

reading a calibration pattern on the disc, the calibration pattern including a plurality of calibration pits corresponding to the various discrete data levels;

calibrating the analog to digital signal conversion based upon the calibration pattern reading step; and

synchronizing a disc reader sampling clock based upon the timing of the read calibration pattern.

11. A method as recited in any of the preceding claims wherein each pit has the capacity to store at least 10 discrete data levels and the data level determining step has the capacity to provide at least 10 corresponding digital values.

12. A method as recited in any of the preceding claims wherein the digital data signal includes at least about 2 bits per sample more than the number of bits represented by the potential data levels.

13. A method as recited-in claim 1 further comprising the step of dynamically calibrating the information storage disc, wherein the dynamic calibration includes determining windows having window boundaries which correspond to digital data levels.

14. A method as recited in any of the preceding claims further comprising the step of reading a synchronization pattern on the disc and synchronizing a disc reader sampling clock based upon the timing of the synchronization pattern.

15. A method as recited in claim 14 wherein the synchronization pattern is distinguishable from data which is stored on the disc.

16. A method as recited in any of the preceding claims further comprising the step of analyzing the data signal to determine a frequency and phase of the data signal and synchronizing a disc reader sampling clock based upon the frequency and phase of the data signal.

17. A method for reading data from an optical information storage disc having an information storage track that includes a plurality of pits, each pit having the capacity to store at least three discrete data levels represented by differing intensities of radiation reflected toward a detector comprising:

reading the information storage track and outputting a data signal indicative of the reflectance of the pits;

dynamically calibrating the data signal, wherein the dynamic calibration includes directly or indirectly determining a data signal range corresponding to each of the potential data levels,

sampling the data signal in the vicinity of the location of a particular one of the pits; and

determining from the data signal the discrete data level stored in the sampled pit, there being the potential of at least three discrete data levels that may be represented by the sampled pit, wherein the data level determination is made based on the determined data signal ranges;

whereby the data level read from the sampled pit has the capacity to represent more than one bit of information.

18. A method for reading data from an optical information storage disc having an information storage track that includes a plurality of pits, each pit having the capacity to store at least three discrete data levels represented by differing intensities of radiation reflected toward a detector, the method comprising:

reading an information storage track and outputting a data signal indicative of the reflectance of the pits;

sampling the data signal in the vicinity of the location of a particular one of the pits; and

determining from the data signal the discrete data level stored in the sampled pit, there being the potential of at least three distinct discrete data levels that may be represented by the sampled pit, whereby the digital data read from the sampled pit has the capacity to represent more than one bit of information.

19. An apparatus for reading data from an optical information storage disc having an information storage track that includes a plurality of pits, each pit having the capacity to store at least three discrete data levels represented by differing intensities of radiation reflected toward a detector comprising:

an analog to digital converter configured to sample an analog signal indicative of the reflectance of the pits and configured to provide as an output a digital signal which includes a plurality of bits for each sample,

a digital signal processor configured to determine a discrete data level from the digital data signal, there being the potential of at least three discrete data levels, wherein each potential data level corresponds to an associated range of digital signal values;

whereby the data level read from a pit has the capacity to represent more than one bit of information.

20. An apparatus as recited in claim 19 further comprising:

a calibration processor configured to dynamically calibrate the ranges of digital signal values associated with each potential data level, wherein the dynamic calibration includes directly or indirectly determining a signal range corresponding to each of the potential data levels, and wherein the determined signal ranges are used in determining the

data level read for each sample.

21. An apparatus as recited in claim 20 wherein the calibration processor is configured to calibrate the ranges of digital signal values associated with each potential data level by reading a calibration pattern on the disc, the calibration pattern including a plurality of calibration pits.

22. An apparatus as recited in claim 21 wherein the calibration processor is configured to determine the dynamic range of the analog data signal from a calibration pattern which includes a calibration pit corresponding to the highest data level and a calibration pit corresponding to the lowest data level.

23. An apparatus as recited in claim 21 or claim 22 wherein the calibration processor is configured to determine the ranges of digital signal values associated with each potential data level by reading a calibration pattern on the disc, the calibration pattern including a series of calibration pits corresponding to each of the potential data levels.

24. An apparatus as recited in any one of claims 20-23 wherein the calibration processor is configured to scale the signal ranges according to the dynamic range of the analog data signal.

25. An apparatus as recited in any one of claims 20-23 wherein the calibration processor is configured scale the signal ranges according to the dynamic range of the digital data signal.

26. An apparatus as recited in any one of claims 21-23 wherein the calibration processor is configured to adjust the dynamic range of the analog data signal before the analog data signal is converted to a digital data signal based on the measured dynamic range of the calibration pattern.

27. An apparatus as recited in any one of claims 20-26 wherein the calibration processor is configured to determine the potential number of the discrete data levels that the pits may include from information included on a disc and determine the signal ranges accordingly.

28. An apparatus as recited in any of the preceding claims wherein the digital signal processor is configured to determine a discrete data level from the digital data signal,

there being the potential of at least ten discrete data levels, wherein each potential data level corresponds to an associated range of digital signal values.

29. An apparatus as recited in any of the preceding claims wherein the digital signal includes at least about 2 bits per sample more than the number of bits represented by the potential data levels.

30. An apparatus as recited in claim 19 wherein the calibration processor is configured to determine windows having window boundaries which correspond to digital data levels.

31. An apparatus as recited in any of the preceding claims further comprising a synchronization processor configured to read a pattern on the disc and to synchronize a disc reader sampling clock based upon the timing of the synchronization pattern.

32. An apparatus as recited in claim 31 wherein the synchronization processor is configured to distinguish between a synchronization pattern and the data which is stored on the disc.

33. An apparatus as recited in any of the preceding claims wherein the synchronization processor is configured to analyze the data signal to determine a frequency and phase of the data signal and to synchronize a disc reader sampling clock based upon the frequency and phase of the data signal.

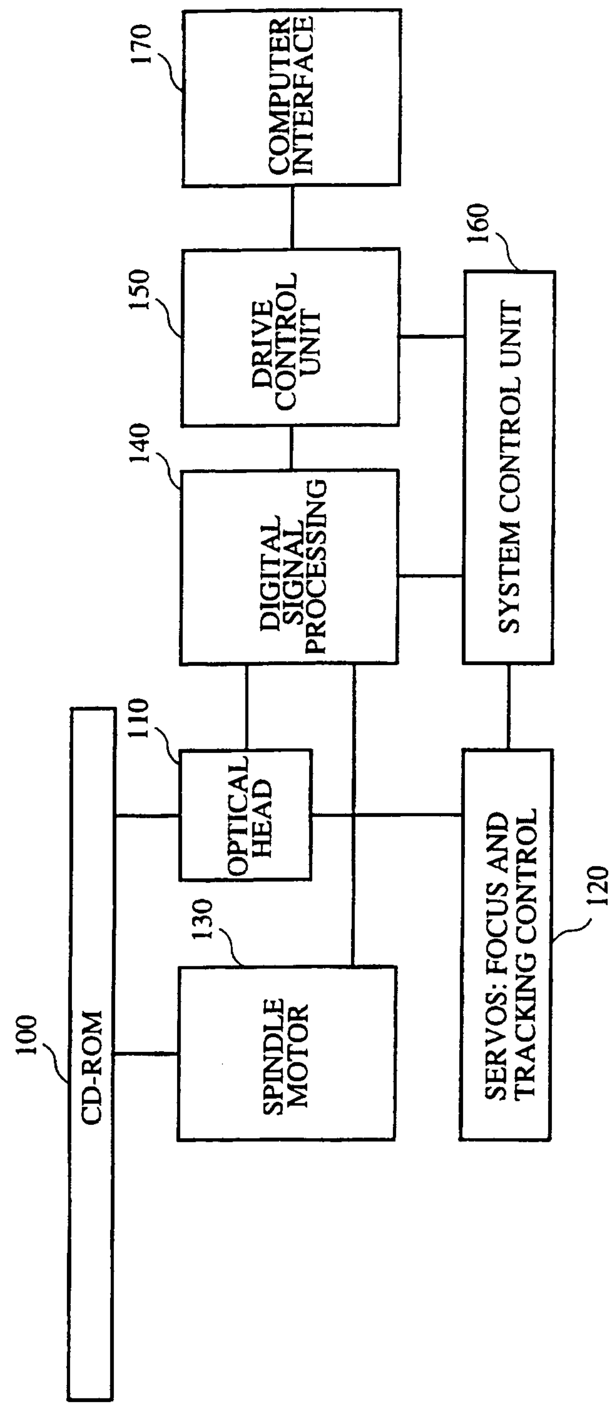


FIG. 1
(Prior Art)

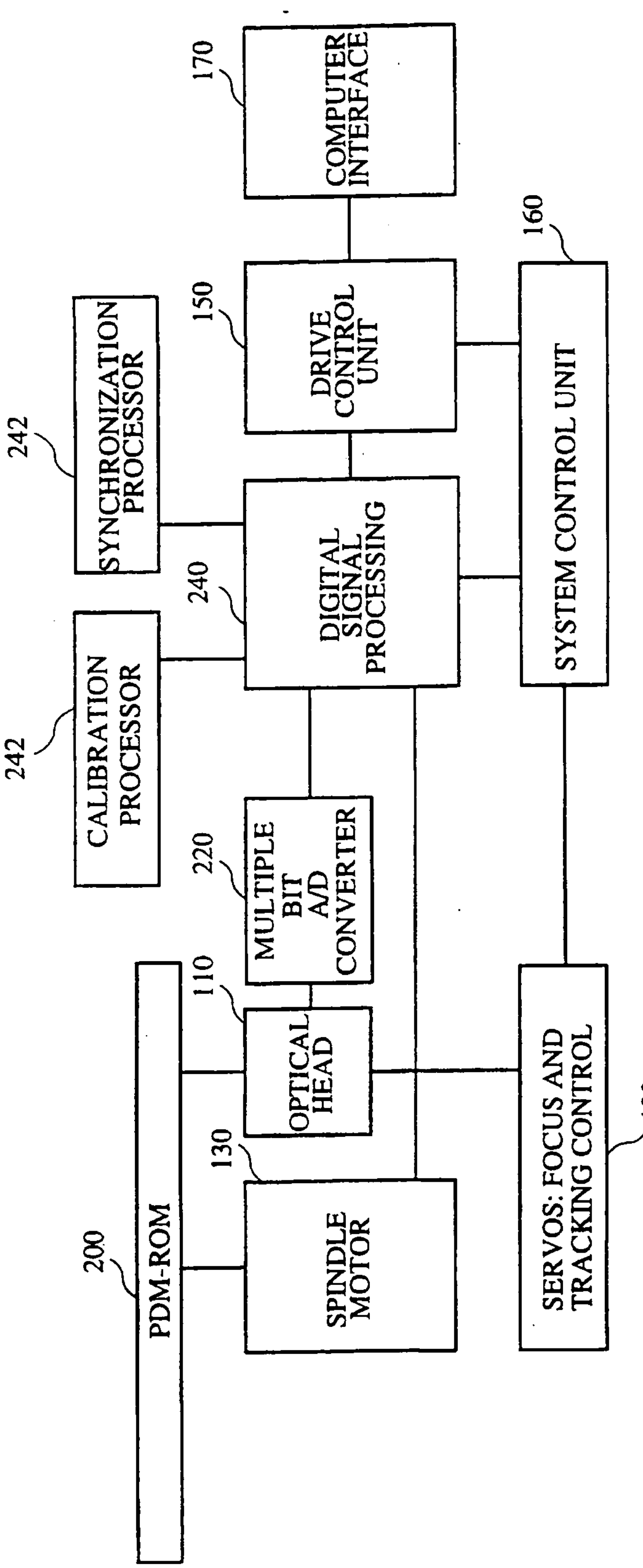

170
COMPUTER INTERFACE
150
DRIVE CONTROL UNIT
160
SYSTEM CONTROL UNIT
242
SYNCHRONIZATION PROCESSOR
240
DIGITAL SIGNAL PROCESSING
242
CALIBRATION PROCESSOR
220
MULTIPLE BIT A/D CONVERTER
110
OPTICAL HEAD
130
SPINDLE MOTOR
200
PDM-ROM
120
SERVOS: FOCUS AND TRACKING CONTROL

FIG. 2A

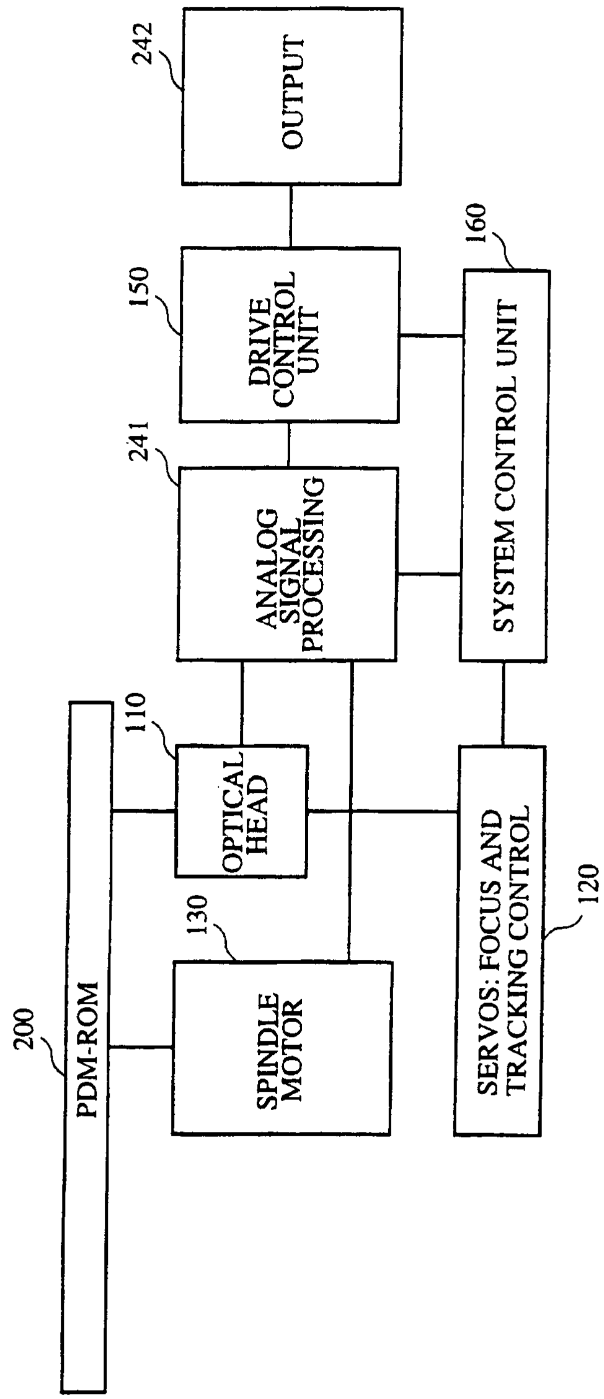

OUTPUT
242
DRIVE CONTROL UNIT
150
SYSTEM CONTROL UNIT
160
ANALOG SIGNAL PROCESSING
241
OPTICAL HEAD
110
SPINDLE MOTOR
130
SERVOS: FOCUS AND TRACKING CONTROL
120
PDM-ROM
200

FIG. 2B

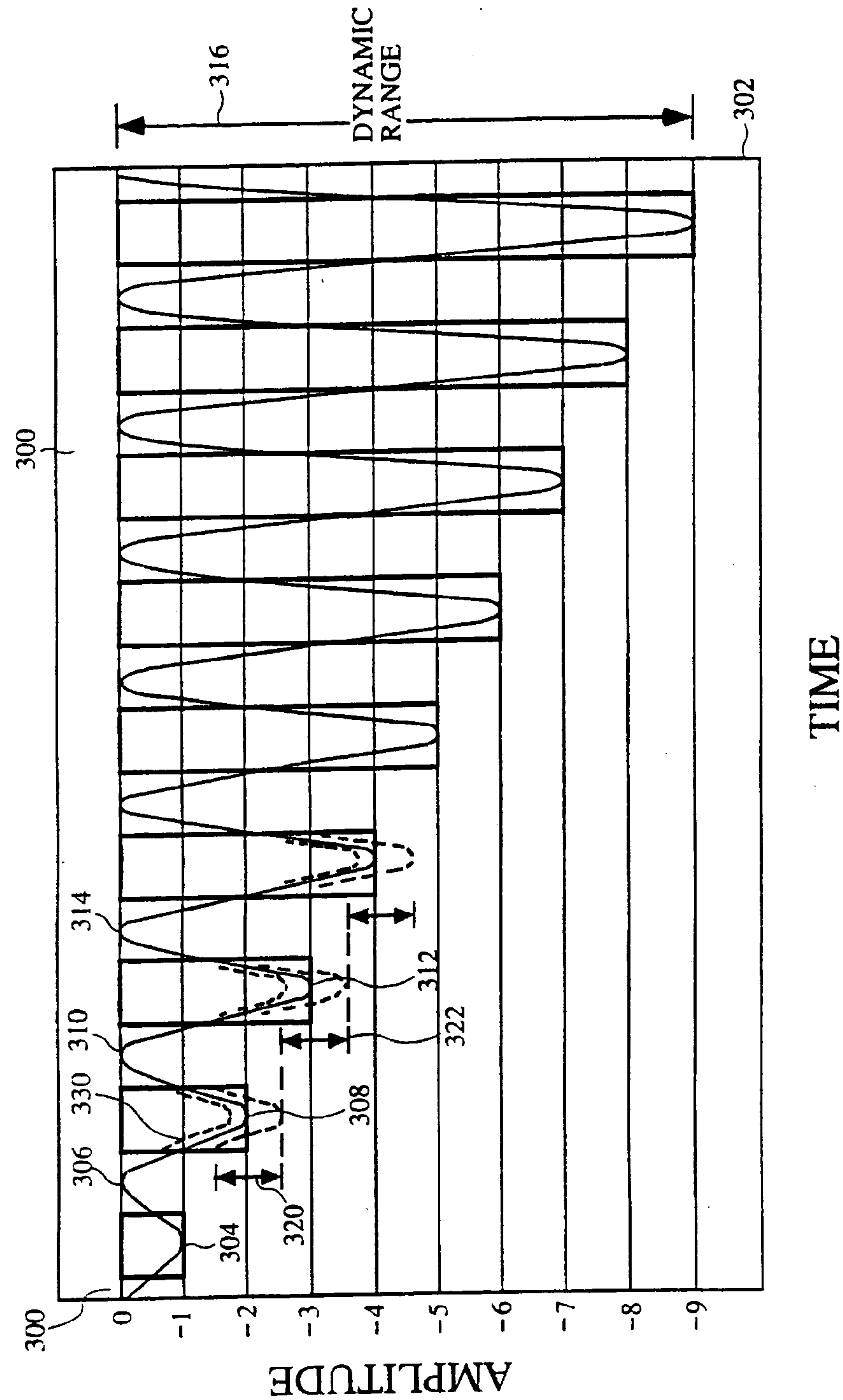

DYNAMIC RANGE
316
302
300
300
314
310
330
306
304
320
308
322
312
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
AMPLITUDE
TIME

FIG.3

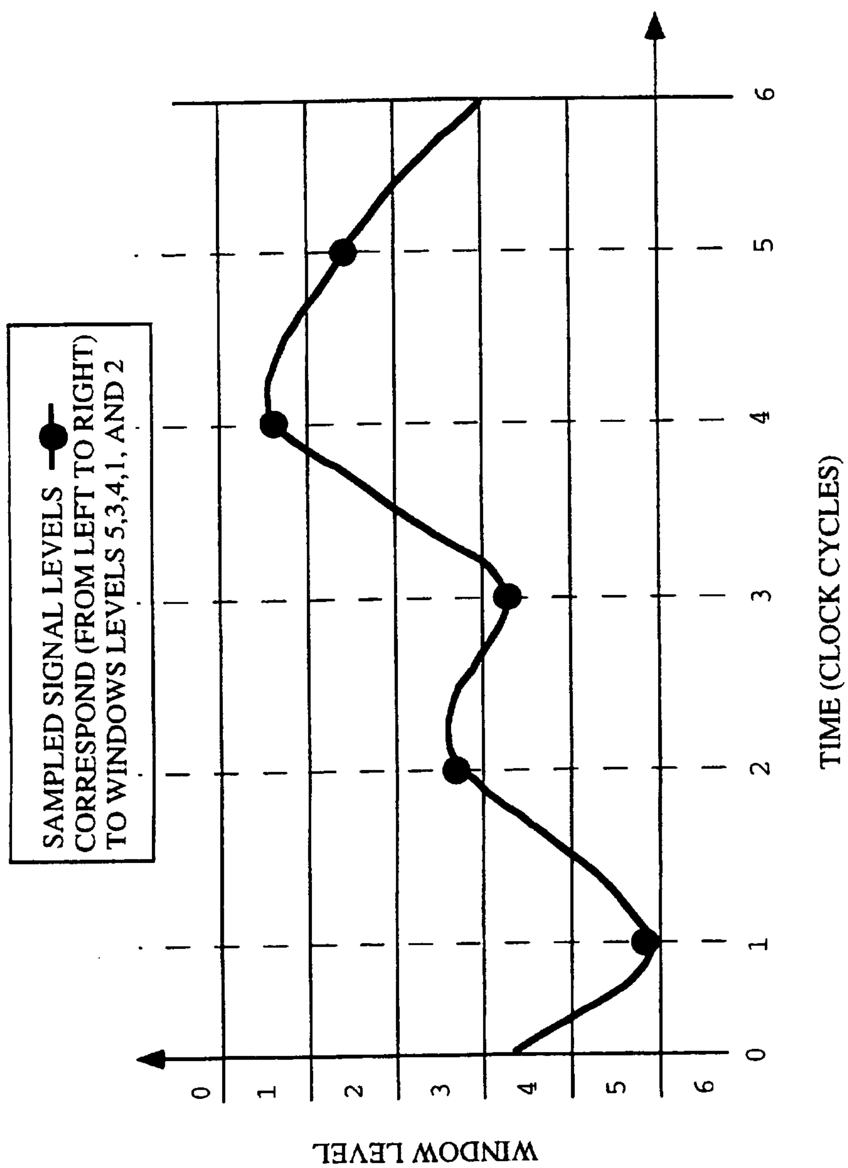

SAMPLED SIGNAL LEVELS CORRESPOND (FROM LEFT TO RIGHT) TO WINDOWS LEVELS 5,3,4,1, AND 2
WINDOW LEVEL
0
1
2
3
4
5
6
TIME (CLOCK CYCLES)
0
1
2
3
4
5
6

FIG.4

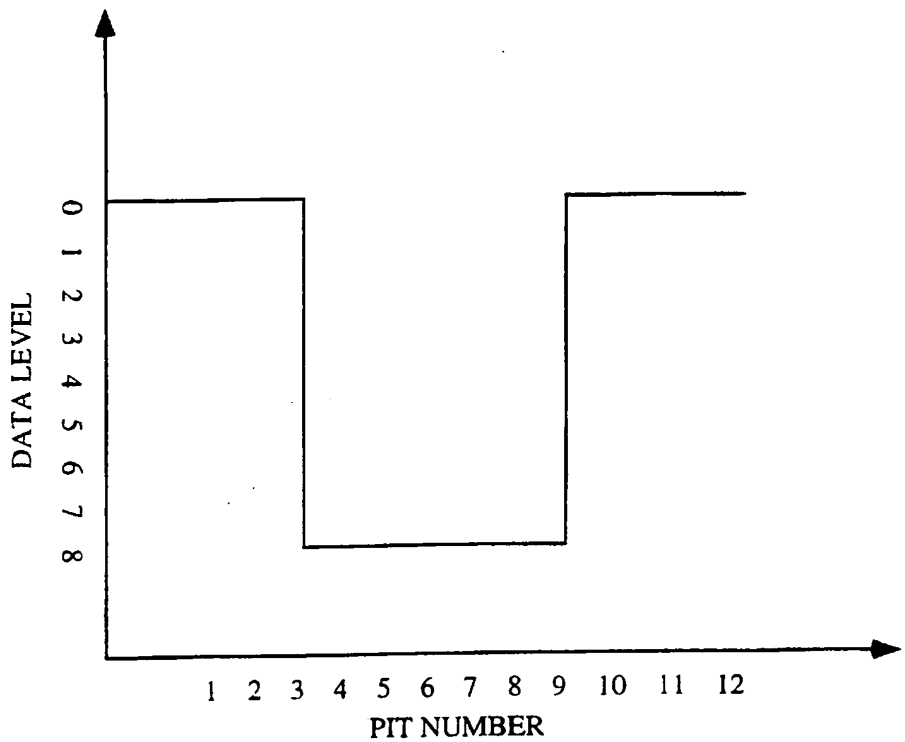

DATA LEVEL
0 1 2 3 4 5 6 7 8
1 2 3 4 5 6 7 8 9 10 11 12
PIT NUMBER

FIG. 5

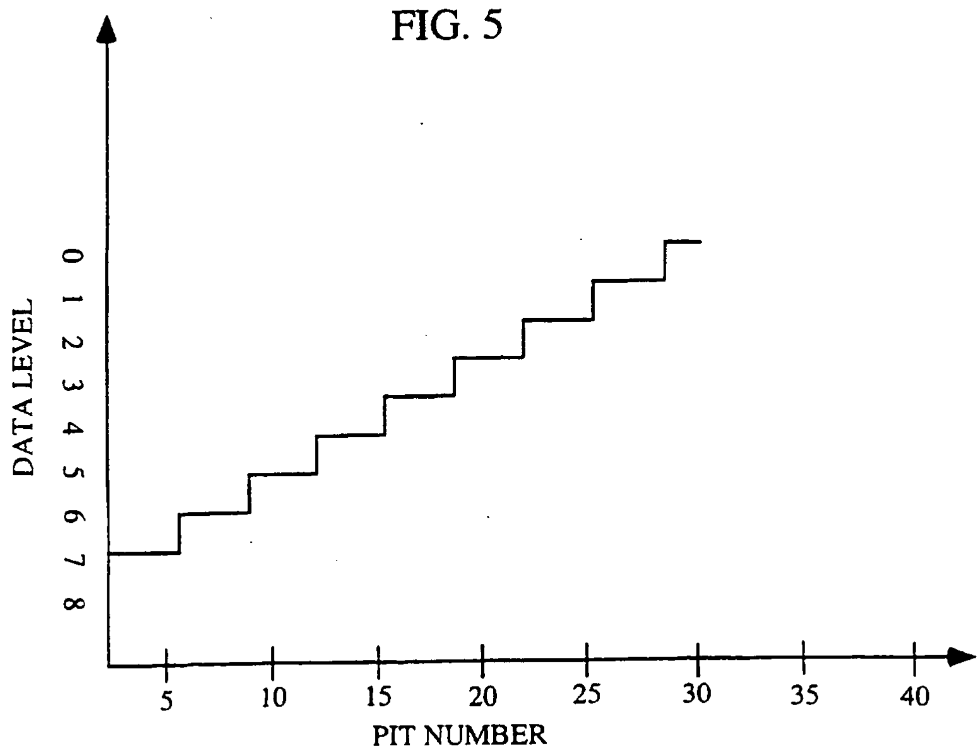

DATA LEVEL
0 1 2 3 4 5 6 7 8
5 10 15 20 25 30 35 40
PIT NUMBER

FIG. 6

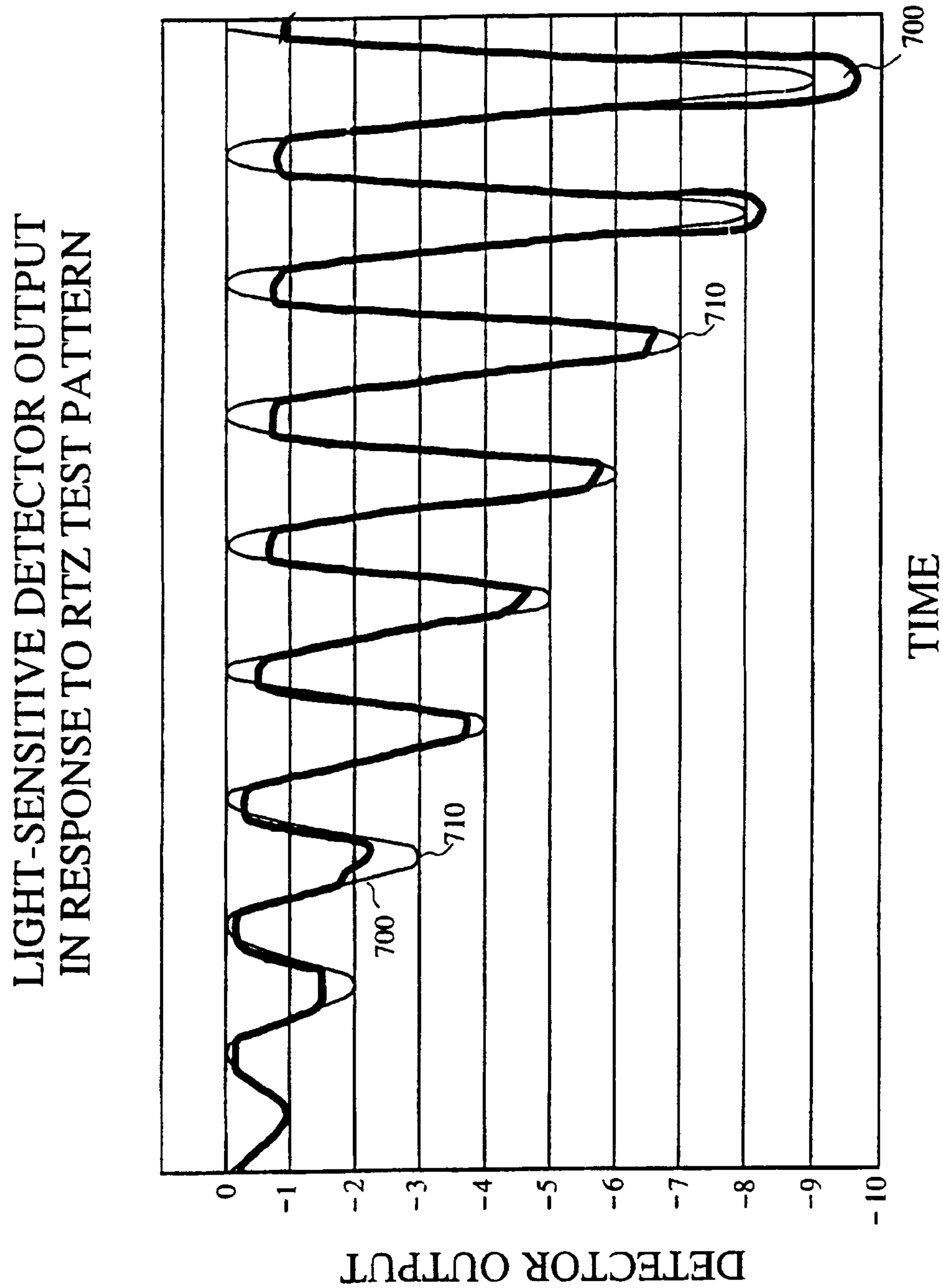

LIGHT-SENSITIVE DETECTOR OUTPUT
IN RESPONSE TO RTZ TEST PATTERN
DETECTOR OUTPUT
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
TIME
700
710
700
710
700

FIG. 7

INTERNATIONAL SEARCH REPORT

Internal Application No
PCT/US 97/00290

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 G11B7/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 G11B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	PATENT ABSTRACTS OF JAPAN vol. 013, no. 428 (P-936), 25 September 1989 & JP 01 159832 A (TOSHIBA CORP), 22 June 1989, see abstract ---	1-5,10, 17-22
X	PATENT ABSTRACTS OF JAPAN vol. 016, no. 024 (P-1301), 21 January 1992 & JP 03 237622 A (CANON INC), 23 October 1991, see abstract ---	1-5,10, 17-22

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier document but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
"&" document member of the same patent family

2

Date of the actual completion of the international search	Date of mailing of the international search report
22 May 1997	30.06.97

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Bernas, Y

Form PCT/ISA/210 (second sheet) (July 1992)

International Application No
PCT/US 97/00290

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	PATENT ABSTRACTS OF JAPAN vol. 016, no. 555 (P-1454), 25 November 1992 & JP 04 209320 A (TOSHIBA CORP), 30 July 1992, see abstract	1-5,10, 17-22
X	PATENT ABSTRACTS OF JAPAN vol. 12, no. 408 (P-778), 28 October 1988 & JP 63 146224 A (HITACHI LTD.), 18 June 1988, see abstract	1-5,10, 17-22
X	US 5 408 456 A (HOSOYA HIDEKI) 18 April 1995 see claims 1,2,4,5; figures 11,12	1,18,19
P,X	EP 0 709 837 A (SONY CORP) 1 May 1996 see claim 1; figure 7	1-5,10, 17-22
A	US 5 235 587 A (BEARDEN ALAN J ET AL) 10 August 1993 cited in the application see claim 1; figure 1	1,17-19

2

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/US 97/00290

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5408456 A	18-04-95	JP 3228226 A	09-10-91
		JP 3228227 A	09-10-91
		JP 3228228 A	09-10-91
		JP 3288331 A	18-12-91
EP 0709837 A	01-05-96	JP 8180496 A	12-07-96
US 5235587 A	10-08-93	US 5029023 A	02-07-91
		AU 639496 B	29-07-93
		AU 6535890 A	28-04-91
		CA 2066202 A	30-03-91
		EP 0494255 A	15-07-92
		JP 5501004 T	25-02-93
		WO 9105336 A	18-04-91